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Federal Communication Commission  
Washington, D.C. 20554  
August 11<sup>th</sup>, 2016

FCC Mailroom

RE: NPRM (WT Docket 16-239) and Petition for Rule Making RM-11708

In opposition to the above PRM, I would like to submit the following comments.

A. Bit, Symbol, and Baud rates

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The A.R.R.L. stated on Page 3 of RM-11708 that, "Such an approach would also standardize the criterion used to determine the permissibility of data transmissions, and it would eliminate the confusion that often exists between symbol rate and baud rate."

A cursory search of articles will find, for example, an excellent article by Lou Frenzel (W5LEF, author and professor of electronics) in *Electronic Design* of April 27, 2012, that explains Bandwidth, Bit, Symbol, and Baud rates, and is included in Addendum A. Therefore, the only confusion on this subject seems to exist within the A.R.R.L. and not the general public.

B. Digital Transmission Systems and Emergency Scenarios

Much has been alluded to regarding digital communications in emergency situations. I would like to examine an emergency scenario. Since there are really no "typical" emergency scenarios, let us define some boundary conditions: a.) AC Power has failed due to a tornado in the area downing power lines, b.) the operator's antenna and structure is intact, c.) the operator has only a 12 volt Marine battery connected to his modern 100 Watt transceiver which is capable of Single Side-Band, Amplitude Modulation, CW, and Digital modes.

Since the AC has failed, the operator's computer, which contains the necessary software, sound card, or external modem to establish a typical digital mode, is inactive.

The options available for instant emergency communications are: Amplitude Modulation, CW, and Single Side-Band. Since local atmospheric condition are most likely less than optimal, the operator will have to resort to either CW or Single Side-Band modes. The most likely form of communications to 'get through' are first, CW and secondly, Single Side-Band.

Therefore, for emergency communications using the above scenario, digital modes using other than the CW mode are not viable.

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### C. Digital Noise and the Noise Floor

In a recent Public Notice found in the FCC's ET Docket No. 16-191, the TAC requested input to, "...help answer questions about the study of changes to the spectrum noise floor over the past 20 years. Noise in this context denotes unwanted radio frequency (RF) energy from man-made sources."

This document states in part,

"Unlicensed Intentional Radiators, Industrial, Scientific, and Medical (ISM) Radiators, and Licensed Radiators are devices that are designed to generate and emit RF energy by radiation or induction. Cellular phones and base stations, unlicensed wireless routers, Bluetooth devices, broadcast TV and radio stations, and radars of many types, are all examples of licensed / unlicensed intentional radiators, and microwave ovens, arc welders, and fluorescent lighting are examples of ISM equipment. *Such emitters contribute to the noise floor with emissions outside of their assigned frequencies.* These are sometimes generated as spurious emissions, including, but not limited to, harmonics of desired frequencies and intermodulation products. Regulations that permit the operation of these devices also specify the limits of emissions outside of licensed or allowed (in the case of unlicensed devices) frequencies of operation." Emphasis mine.

Please further note that "...Cellular phones and base stations, unlicensed wireless routers, Bluetooth devices..." are all systems and devices based on wide-band digital protocols. Therefore, logic dictates that increased use of wide-band digital protocols can only raise the global noise floor, especially in the Amateur Radio Service.

### D. PACTOR and other Data Protocol Systems

Referencing Page 9 (Section 3, paragraph 10) of the ARRL's PRM RM-11708 document of November 15<sup>th</sup>, 2013, we find the following statement: "Conversely, the artificial limitation of symbol rate *precludes* the use of newer, more efficient data communications modes which utilize lower bandwidths which meet the symbol rate limitation." Emphasis mine.

I would like to present a few examples of data systems that are currently in use and are Open-Source systems. These systems require much less passband than the PACTOR 4 system. Passbands values are approximate and rounded up.

1. Morse Code (CW). This method of course is arguably the oldest known digital method. Using on-off carrier modulation at a rate of 13 Words-per-Minute, and with a waveform rise and fall time of approximately 15 ms, the bandwidth is 52 Hz.
2. PSK-31. This system uses PSK or QPSK modulation techniques and has a passband of 32 Hz.
3. JT-65. Originally used for EME communications, this system uses a 65-tone FSK system. The passband for JT-65A is 355 Hz.
4. RTTY. At 100 words-per-minute and a 75 Baud symbol rate, the passband is 370 Hz.

Please note the references in the A.R.R.L. RM-11708 document, especially Page 8, with regards to the PACTOR 4 system. This system requires a minimum passband of 2.4 kHz. (See: Special Communications Systems, SCS's document at, [http://www.p4dragon.com/download/InstallationGuide\\_DR-7X00.pdf](http://www.p4dragon.com/download/InstallationGuide_DR-7X00.pdf), Page 56).

Therefore, there are more efficient data protocols available with spectrum conserving bandwidths.

#### E. Comment regarding Future Directions in the Amateur Radio Service.

Philosophically speaking, a deeper question the Amateur Radio community must ask itself is this: do you, the amateur radio operator want to continue with Voice and narrow passband digital systems (such as those listed above in D., 1-4), or do you want the ARS to become an extension of the Internet cluttered with digital signals occupying, at minimum the bandwidth of voice modes, and raising the noise floor?

#### F. Digital Interference to Analog Modes

One of the interference problems encountered on the phone bands is that of digital image vs. analog phone, i.e., Digital Image and other digital operators causing QRM to analog phone. One solution would be to relegate these "image" transmissions to a data sub-band. An additional requirement would be that *all* digital modes attach a CW ID in order to identify senders. This would be completely unobtrusive and easy with software.

#### G. Conclusion.

I agree with the FCC's conclusion stated in Section IV, "...We do not, however, propose a bandwidth limitation for data emissions in the MF and HF bands to replace the baud rate limitations, because the rule's current approach for limiting bandwidth use by amateur stations using one of the specified digital codes to encode the signal being transmitted appears sufficient to ensure that general access to the band by licensees in the amateur service does not become unduly impaired."

In this author's view, the advancement of technology will continue to develop enhanced, narrow passband digital protocols and methods to achieve additional throughput, without having to resort to wideband digital methods such as those promoted by the A.R.R.L. and SCS's PACTOR 4.

A rejection of RM-11708 can only advance the development of newer digital transmission protocols for the amateur service.

Kindly regards,

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## Addendum A:

### What's The Difference Between Bit Rate and Baud Rate?

Apr 27, 2012 Lou Frenzel | *Electronic Design*

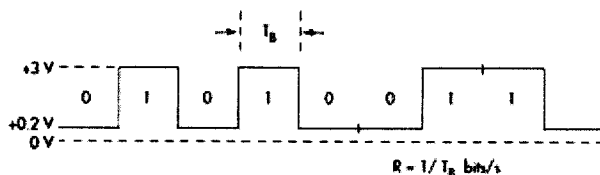
Serial-data speed is usually stated in terms of bit rate. However, another oft-quoted measure of speed is baud rate. Though the two aren't the same, similarities exist under some circumstances. This tutorial will make the difference clear.

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#### Background

Most data communications over networks occurs via serial-data transmission. Data bits transmit one at a time over some communications channel, such as a cable or a wireless path. Figure 1 typifies the digital-bit pattern from a computer or some other digital circuit. This data signal is often called the baseband signal. The data switches between two voltage levels, such as +3 V for a binary 1 and +0.2 V for a binary 0. Other binary levels are also used. In the non-return-to-zero (NRZ) format (*Fig. 1, again*), the signal never goes to zero as like that of return-to-zero (RZ) formatted signals.



1. Non-return to zero (NRZ) is the most common binary data format. Data rate is indicated in bits per second (bits/s).

#### Bit Rate

The speed of the data is expressed in bits per second (bits/s or bps). The data rate  $R$  is a function of the duration of the bit or bit time ( $T_B$ ) (*Fig. 1, again*):

$$R = 1/T_B$$

Rate is also called channel capacity  $C$ . If the bit time is 10 ns, the data rate equals:

$$R = 1/10 \times 10^{-9} = 100 \text{ million bits/s}$$

This is usually expressed as 100 Mbits/s.

#### Overhead

Bit rate is typically seen in terms of the actual data rate. Yet for most serial transmissions, the data represents part of a more complex protocol frame or packet format, which includes bits representing source address, destination address, error detection and correction codes, and other information or control bits. In the protocol frame, the data is called the “payload.” Non-data bits are known as the “overhead.” At times, the overhead may be substantial—up to 20% to 50% depending on the total payload bits sent over the channel.

For example, an Ethernet frame can have as many as 1542 bytes or octets, depending on the data payload. Payload can range from 42 to 1500 octets. With a maximum payload, the overhead is only  $42/1542 = 0.027$ , or about 2.7%. It would be even greater if the payload was anything smaller. This relationship is usually expressed as a percentage of the payload size to the maximum frame size, otherwise known as the protocol efficiency:

$$\text{Protocol efficiency} = \text{payload/frame size} = 1500/1542 = 0.9727 \text{ or } 97.3\%$$

Typically, the actual line rate is stepped up by a factor influenced by the overhead to achieve an actual target net data rate. In One Gigabit Ethernet, the actual line rate is 1.25 Gbits/s to achieve a net payload throughput of 1 Gbit/s. In a 10-Gbit/s Ethernet system, gross data rate equals 10.3125 Gbits/s to achieve a true data rate of 10 Gbits/s. The net data rate also is referred to as the throughput, or payload rate, of effective data rate.

## Baud Rate

The term “baud” originates from the French engineer Emile Baudot, who invented the 5-bit teletype code. Baud rate refers to the number of signal or symbol changes that occur per second. A symbol is one of several voltage, frequency, or phase changes.

NRZ binary has two symbols, one for each bit 0 or 1, that represent voltage levels. In this case, the baud or symbol rate is the same as the bit rate. However, it's possible to have more than two symbols per transmission interval, whereby each symbol represents multiple bits. With more than two symbols, data is transmitted using modulation techniques.

When the transmission medium can't handle the baseband data, modulation enters the picture. Of course, this is true of wireless. Baseband binary signals can't be transmitted directly; rather, the data is modulated on to a radio carrier for transmission. Some cable connections even use modulation to increase the data rate, which is referred to as “broadband transmission.”

By using multiple symbols, multiple bits can be transmitted per symbol. For example, if the symbol rate is 4800 baud and each symbol represents two bits, that translates into an overall bit rate of 9600 bits/s. Normally the number of symbols is some power of two. If  $N$  is the number of bits per symbol, then the number of required symbols is  $S = 2^N$ . Thus, the gross bit rate is:

$$R = \text{baud rate} \times \log_2 S = \text{baud rate} \times 3.32 \log_{10} S$$

If the baud rate is 4800 and there are two bits per symbol, the number of symbols is  $2_2 = 4$ . The bit rate is:

$$R = 4800 \times 3.32 \log(4) = 4800 \times 2 = 9600 \text{ bits/s}$$

If there's only one bit per symbol, as is the case with binary NRZ, the bit and baud rates remain the same.

## Multilevel Modulation

Many different modulation schemes can implement high bit rates. For example, frequency-shift keying (FSK) typically uses two different frequencies in each symbol interval to represent binary 0 and 1. Therefore, the bit rate is equal to the baud rate. However, if each symbol represents two bits, it requires the four frequencies (4FSK). In 4FSK, the bit rate is two times the baud rate.

Phase-shift keying (PSK) is another popular example. When employing binary PSK, each symbol represents a 0 or 1 (*see the table*). A binary 0 equals  $0^\circ$ , while a binary 1 is  $180^\circ$ . With

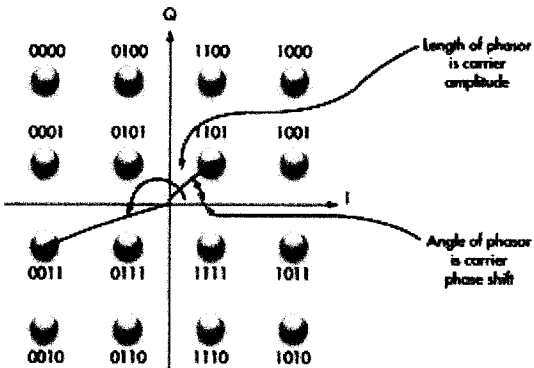
one bit per symbol, the baud and bit rates are the same. However, multiple bits per symbol can be easily implemented.

BINARY PHASE-SHIFT KEYING	
Bit	Phase shift (degrees)
0 0	45
0 1	135
1 1	225
1 0	315

For instance, in quadrature PSK there are two bits per symbol. Using this arrangement and two bits per baud, the bit rate is twice the baud rate. Other forms of PSK use more bits per baud. With three bits per baud, the modulation becomes 8PSK for eight different phase shifts representing three bits. And with 16PSK, 16 phase shifts represent the four bits per symbol.

One unique form of multilevel modulation is quadrature amplitude modulation (QAM). QAM uses a mix of different amplitude levels and phase shifts to create the symbols representing multiple bits. For example, 16QAM encodes four bits per symbol. The symbols are a mix of different amplitude levels and different phase shifts.

A constellation diagram is typically used to illustrate the amplitude and phase conditions of the carrier for each 4-bit code (*Fig. 2*). Each dot represents a specific carrier amplitude and phase shift. A total of 16 symbols encodes four bits per symbol, ultimately quadrupling the bit rate over the baud rate.



2. A constellation diagram for 16QAM shows the 16 possible carrier amplitude and phase combinations representing four bits per symbol.

Why Multiple Bits Per Baud?

By transmitting more than one bit per baud, higher data rates can be transmitted in a narrower channel. Recall that the maximum possible data rate is determined by the bandwidth of the transmission channel.

Assuming a worse case of alternating 1s and 0s of data, the maximum theoretical bit rate  $C$  for a given bandwidth  $B$  is:

$$C = 2B$$

Or the bandwidth for a maximum bit rate is:

$$B = C/2$$

Transmitting a 1-Mbit/s signal requires:

$$B = 1/2 = 0.5 \text{ MHz or } 500 \text{ kHz}$$

When using multilevel modulation with multiple bits per symbol, the maximum theoretical data rate is:

$$C = 2B \log_2 N$$

Here,  $N$  is the number of symbols per symbol interval:

$$\log_2 N = 3.32 \log_{10} N$$



The bandwidth needed with a specific number of different levels for a desired speed is calculated as:

$$B = C/2 \log_2 N$$

For instance, the bandwidth needed to get a 1-Mbit/s data rate with two bits per symbol and four levels can be determined with:

$$\log_2 N = 3.32 \log_{10}(4) = 2$$

$$B = 1/2(2) = 1/4 = 0.25 \text{ MHz}$$

The number of symbols needed to get a desired data rate in a fixed bandwidth can be calculated as:

$$\log_2 N = C/2B$$

$$3.32 \log_{10} N = C/2B$$

$$\log_{10} N = C/2B = C/6.64B$$

Then:

$$N = \log^{-1} (C/6.64B)$$

Using the previous example, the number of symbols needed to transmit 1 Mbit/s in a 250-kHz channel is calculated as:

$$\log_{10} N = C/6.64B = 1/6.64(0.25) = 0.602$$

$$N = \log^{-1} (0.602) = 4 \text{ symbols}$$

These calculations assume a noise-free channel. Factoring in the noise requires the well-known Shannon-Hartley law:

$$C = B \log_2 (S/N + 1)$$

C is the channel capacity in bits per second and B is the bandwidth in hertz. S/N is the signal-to-noise power ratio.

In terms of common logarithms:

$$C = 3.32B \log_{10}(S/N + 1)$$

What is the maximum rate in a 0.25-MHz channel with a 30-dB S/N? The 30 dB translates to a 1000 to 1 S/N. Therefore, the maximum rate is:

$$C = 3.32B \log_{10}(S/N + 1) = 3.32(.25) \log_{10}(1001) = 2.5 \text{ Mbits/s}$$

The Shannon-Hartley law doesn't specifically state that multilevel modulation must be employed to achieve that theoretical result. Using the previous procedure will reveal how many bits per symbol are required:

$$\log_{10}N = C/6.64B = 2.5/6.64(0.25) = 1.5$$

$$N = \log^{-1}(1.5) = 32 \text{ symbols}$$

Using 32 symbols implies five bits per symbol ( $2^5 = 32$ ).

#### Baud Rate Examples

Virtually all high-speed data connections use some form of broadband transmission. Wi-Fi wireless takes advantage of QPSK, 16QAM, and 64QAM in the orthogonal frequency-division multiplex (OFDM) modulation schemes. The same is true for WiMAX and Long-Term Evolution (LTE) 4G cellular technology. Cable TV and its high-speed Internet access exploit 16QAM and 64QAM to deliver analog and digital TV, while satellites use QPSK and various versions of QAM.

Land mobile radio (LMR) systems for public safety recently adopted standards for voice and data 4FSK modulation. This "narrowbanding" effort is designed to reduce the bandwidth needed from 25 kHz per channel to 12.5 kHz, and eventually 6.25 kHz. As a result, there will be more channels for additional radios without increasing the spectrum allocations.

U.S. high-definition TV employs a modulation method called eight-level vestigial sideband, or 8VSB. This method uses three bits per symbol for eight amplitude levels, which enables the transmission of 10,800 symbols/s. At 3 bits per symbol, that represents a gross bit rate of  $3 \times 10,800 = 32.4 \text{ Mbits/s}$ . When combined with the VSB, which only transmits one full sideband and a vestige of another, high-definition video and audio can be transmitted in a 6-MHz-wide TV channel.

## References

1. Frenzel, Louis E., *Principles of Electronic Communication Systems*, McGraw-Hill, 2008.
2. Gibson, Jerry D., *The Communications Handbook*, CRC Press/IEEE Press, 1997.
3. Sklar, Bernard, *Digital Communications, Fundamentals and Applications*, Prentice-Hall, 2001.